

DESIGN, CONSTRUCTION, AND EVALUATION
OF A GAS FORGE

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OF A GAS FORGE

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PREFACE OR ACKNOWLEDGEMENTS

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ABSTRACT

This report covers the design, construction, and evaluation of a propane forge. The purpose for building this propane forge was to replace an old charcoal forge in order to improve upon certain points of performance such as adjustability of heat, portability, and fuel cost by being able to run the forge for any amount of time with an easy on/off control. The design of this forge consisted of a steel pipe body insulated with ceramic fiber blanket, and was heated by a single atmospheric burner.

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TABLE OF CONTENTS

| | <u>PAGE</u> |
|-----------------------------|-------------|
| SIGNATURE PAGE----- | ii |
| ACKNOWLEDGEMENTS----- | iii |
| ABSTRACT----- | iv |
| DISCLAIMER STATEMENT----- | v |
| LIST OF FIGURES----- | vii |
| LIST OF TABLES----- | viii |
| INTRODUCTION----- | 1 |
| LITERATURE RREVIEW----- | 3 |
| PROCEDURES AND METHODS----- | 5 |
| Design Procedure----- | 5 |
| Construction Procedure----- | 8 |
| RESULTS----- | 19 |
| DISCUSSION----- | 20 |
| RECOMMENDATIONS----- | 22 |
| REFERENCES----- | 23 |
| APPENDICES----- | 24 |

LIST OF FIGURES

| | <u>PAGE</u> |
|--|-------------|
| Figure 1: Blacksmiths Using Archaic Forge ----- | 1 |
| Figure 2: Forge Design Drawing ----- | 5 |
| Figure 3: Burner Diagram ----- | 7 |
| Figure 4: Cutting Body to Length ----- | 8 |
| Figure 5: Laying Out Holes on the Burner Holder ----- | 9 |
| Figure 6: Rebar Handle Drawing----- | 10 |
| Figure 7: Angle Iron Feet----- | 11 |
| Figure 8: Toolstand----- | 12 |
| Figure 9: Spray Painting the Body with High-Heat Spray Paint----- | 12 |
| Figure 10: Flaring the Nozzle over Round Stock----- | 14 |
| Figure 11: Tapping the Set Screw Holes on the Burner Nozzle----- | 15 |
| Figure 12: Tapering Burner Tube on Bench Grinder----- | 16 |
| Figure 13: Fully Constructed Forge Body----- | 16 |
| Figure 14: Rear Wall Installed with Front Bricks Stacked in Place----- | 17 |
| Figure 15: Forge with Fiber Blanket Installed----- | 18 |
| Figure 16: Painting ITC-100 Onto the Fiber Blanket----- | 18 |
| Figure 17: Forge User with Forged Knife----- | 19 |

LIST OF TABLES

| | <u>PAGE</u> |
|--------------------------------------|-------------|
| Table 1: Propane Gas Properties----- | 3 |
| Table 2: Coal Properties----- | 4 |

INTRODUCTION

Since the beginning of time, man has found the need to use tools to help him accomplish his work. One of the first tools was the blade. Starting from crude elements, man found better ways to make the blades that met societal needs along with advances in technology. Through the ages, the materials and quality of man's blades increased. For many centuries, man relied on the edged weapon as a means of survival from daily life to warfare. From the Japanese Katana to the American Bowie knife, the blade has become a historical and iconic piece for civilizations as well as a unique art form among people as is seen in Figure1 below. While the process of forging a blade has changed over the course of history, man's need for the blade has not diminished any.

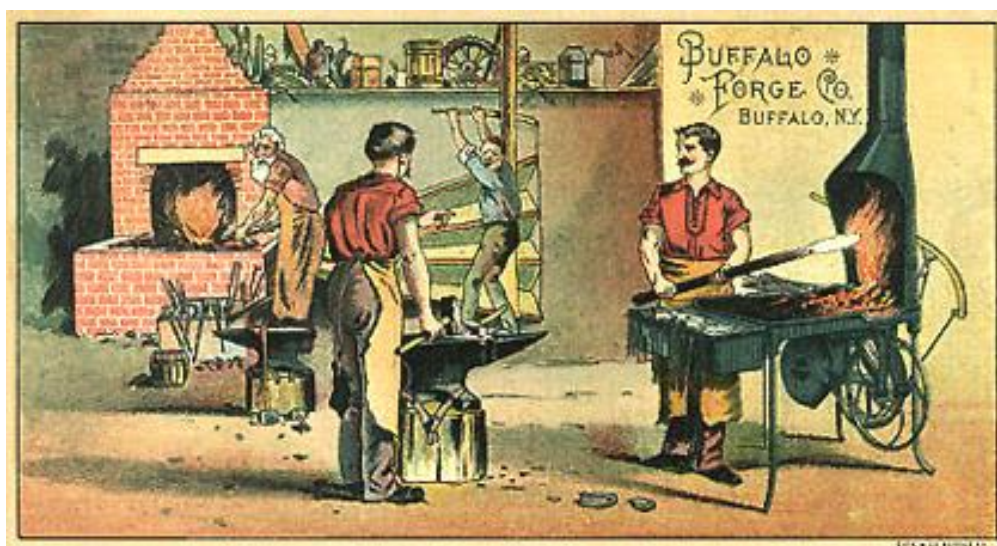


Figure 1. Blacksmiths Using Archaic Forge (blackiron.us).

To create a hardened blade that can withstand repeated use and hold an edge, knife makers temper and heat treat the blade. To harden the blade, it must be heated to a high temperature then quickly cooled in a liquid. The process of heating a blade takes place in a forge. A forge is a device that can harbor an environment of extreme heat by providing and containing a concentrated heat source. Forges use various methods to provide the heat.

Ashton Davis currently uses a homemade charcoal forge to make knives and metalwork. His current forge consists of a cast iron pot which is filled with coals, and air-fed by an air compressor through a PVC pipe. The problems with coal and charcoal forges are that they cannot easily be turned off or on, the

temperature is difficult to control, and poor quality charcoal can adversely affect the blades by causing impurities. By switching to a propane powered forge, those problems would be eliminated by allowing it to easily be turned off or on, being able to control the gas flow, and eliminating the possibility of poor quality charcoal. Propane heat is still able to reach forge welding temperatures so the capabilities of the forge are not diminished. The project is to design, build, and test a propane forge that will improve the quality and ease of knife making over a coal forge and is big enough to fit other tools such as hammers and hatchets for forge work but can be lifted by a single man.

LITERATURE REVIEW

Research was conducted in order to examine existing methods for metalworking for hobbyists. Much information regarding propane forges, including DIY guides on making propane forges, can be found on the internet. There are numerous videos, pictures, and articles describing relatively easy ways to construct homemade propane forges. Information from a few articles will be compiled and used for the final project plan. Propane is nearly twice as energy dense as coal (see Tables 1 and 2 below) and charcoal energy density is usually around the high values of coal given in Table 2.

As for composition of the forge itself, the main body can be a cylindrical piece of steel. Dempsey (2005) claims that a body as thin as 14ga steel will work if proper insulation is installed because it will not get too hot. A forge must be heated by a burner, for which there are a couple of options to go with. From the review, the RR type EZ burner has the ability to reach forge welding temperatures without requiring a blower. This burner is recommended for sea level areas, and is simple to construct from parts purchased at a local plumbing store. This burner is said to be a good beginner burner and can be easily replaced by a more advanced burner (adjustable) at a later time (Dempsey, 2005). The article also talks about the front and back of the forge and what to do about retaining heat. Dempsey (2005) says that there should be a small hole in the back so that long pieces can extend

| Approximate Properties Of LP-Gases (Commercial Propane) | | | |
|--|----------|---|-------------------------------|
| Specific gravity of liquid at 60 degrees F | 0.504 | Latent heat of vaporization at boiling point: | |
| Initial boiling point at 14.7 psia, degrees F | -44.0 | (a) Btu per pound | 184 |
| Weight per gallon of liquid at 60 degrees F, lb | 4.20 | (b) Btu per gallon | 773 |
| Specific heat of liquid, Btu/lb. At 60 degrees F | 0.630 | Total heating values after vaporization: | |
| Cubic ft. of vapor per gallon at 60 degrees F | 36.38 | (a) Btu per cubic foot | 2,488 |
| Cubic ft. of vapor per pound at 60 degrees F | 8.66 | (b) Btu per pound | 21,548 |
| Specific gravity of vapor (air=1) at 60 degrees F | 1.50 | (c) Btu per gallon | 91,502 |
| Ignition temperature in air, degrees F | 920-1120 | Molecular weight | 44.094 |
| Maximum flame temperature in air, degrees F | 3,595 | Chemical formula | C ₃ H ₈ |
| Limits of flammability in air, Percent of vapor in air-gas mixture: | | Vapor pressure in psig | |
| (a) Lower | 2.15 | 70 degrees F | 127 |
| (b) Upper | 9.60 | 100 degrees F | 196 |
| | | 105 degrees F | 210 |
| | | 130 degrees F | 287 |

Table 1. Propane Gas Properties (NFPA 1998).

through the opening and so that expanding hot gases have a place to escape. For the front, it should be large and open, but have soft firebricks to stack and close off the front to heat it up to retain heat. The rule of thumb for the vent is at least seven times the cross sectional area of the burner.

| Coal Grade | Heating Value | |
|----------------------------|---------------|---------|
| | (Btu/lb) | (kJ/kg) |
| Anthracite | 12910 | 30080 |
| Semi-Anthracite | 13770 | 32084 |
| Low-volatile bituminous | 14340 | 33412 |
| Medium-volatile bituminous | 13840 | 32247 |
| High-volatile bituminous A | 13090 | 30499 |
| High-volatile bituminous B | 12130 | 28262 |
| High-volatile bituminous C | 10750 | 25047 |
| Sub-bituminous B | 9150 | 21319 |
| Sub-bituminous C | 8940 | 20830 |
| Lignite | 6900 | 16077 |

Table 2. Coal Properties (Engineering ToolBox).

Another article described the need for fiber lining inside of the forge (Zoeller, 2012). The purpose of it is to keep as much heat within the forge as possible so the heating process is as efficient as possible. There are a few options for insulating the inside of the forge. One option is to use firebrick because it is cheap, but it is also inefficient. Fabric lining is the ideal option because, while it is more expensive, it holds heat much better. Kaowool is one option for the lining that is very common in gas forge construction. From reviewing the specifications of their products on the Morgan: Thermal Ceramics website, the Kaowool ceramic fiber blankets are rated at 1,260 degrees C which is equal to 2,300 degrees F. The combustion temperature of propane is 1,967 degrees F for combustion with air and 2,526 degrees for combustion with pure oxygen (The Engineering ToolBox). Typical forge welding temperatures for a propane forge are accepted as 2,300 degrees F, and common forging can be accomplished at a lower temperature.

The body must be painted so that it will be protected from corrosion. From the review of the products on Home Depot's website, there are many paints that will work for high heat applications, but one is easily obtainable and fits the specifications. Rust-Oleum High Heat has a flat finish and will look nice and will also protect the steel from rust and corrosion. The thing that paint must be able to weather in this application is the heat that it will be subject to. For the outside of the body of the forge, the paint will be subject only to the heat of the steel body itself which is protected from direct contact with the flames by way of the wool fabric refractory lining. The paint is rated for 2,000 degrees F which will be sufficient heat resistance as the steel body of the forge should never get near that temperature.

PROCEDURES AND METHODS

Design

Body. Because this project was meant to replace one device with a new, better device, certain areas had to be focused on for the alteration. The first design consideration was the main body of the apparatus. Since propane forges are enclosed systems with the only openings being vents and access doors or permanent openings, a body had to be created that would be big enough to fit the pieces that would be forged as well as allow for insulation, but not be too big where it could not be carried short distances or lifted chest high by one man.

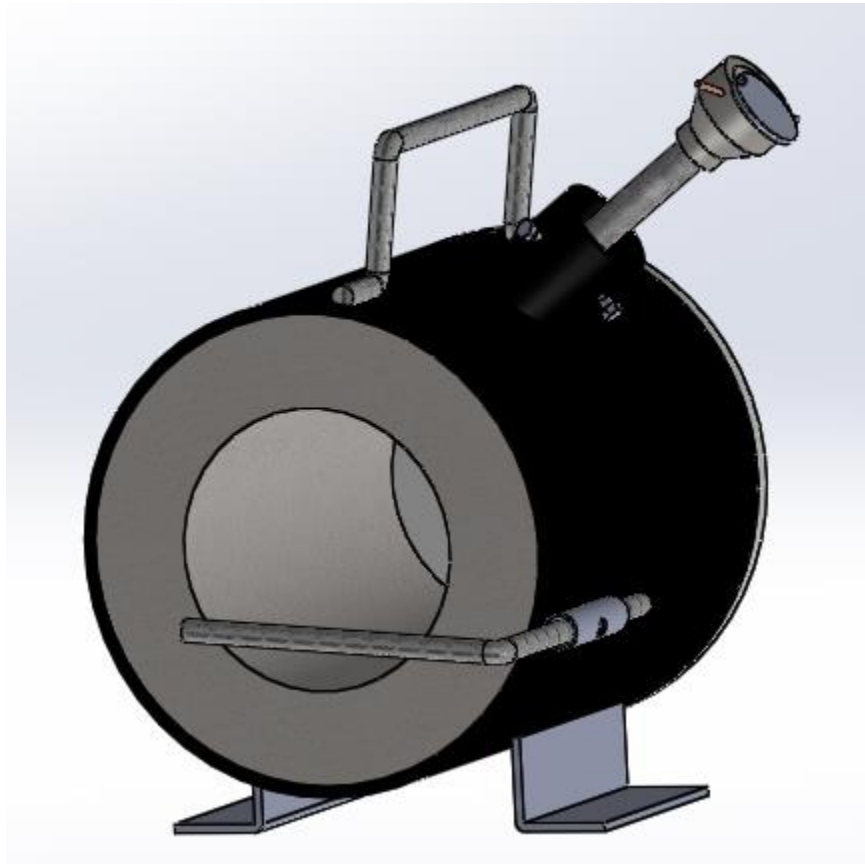


Figure 2. Forge Design Drawing

The other consideration for main body size was the heating required for the space. A rule of thumb in the forging industry is one EZ burner (the burner that was ultimately chosen) per 350 cubic inches of space in the forge in order to reach standard forging temperatures. This design ended up being 339 cubic

inches of The body that was chosen was a 10" ID schedule 40 steel pipe. This was chosen because it was available, however in another instance where one would have to be ordered a different choice may have been made. The body also included two pieces of angle iron for stabilizers at the base of the forge

Insulation. To insulate the inside of the forge, 2" of ceramic fiber blanket insulation was chosen because of its high resistance to extreme heat and its workability in a round pipe. 2" was chosen because of the double effectiveness of retaining the heat in the forge. While it cost more to add the extra layer, lower fuel costs would make up the difference quickly. Like a car with good gas mileage, it costs more to begin with, but requires less fuel to run. The same concept applies with the forge because less heat is escaping the forge with better insulation and the fuel is therefore used more efficiently. The additional cost of installing the second layer of insulation would be \$7.46 since the cost of the blanket is \$4.75 per square foot. The extra fuel cost without the second layer of insulation is \$0.18 per hour (refer to Appendix B). After 26 hours of operating the forge, the second layer of insulation pays itself off and starts saving money. Instead of a single roll of 2" thick fiber blanket, two 1" layers were used because it is easier to work 1" layers in a round body than it is to work a 2" piece. In a box shaped forge, firebricks probably would have been chosen because they are cheaper than the fiber blanket and can easily be stacked during installation. Firebricks also do not emit dangerous fiber particles in the air when the forge is ran such as the fiber blanket does. For this design, a refractory coating called ITC-100 was used to coat the entirety of the fiber blanket. The coating is a clay-like substance that is painted on and dries. This was done because it helps keep heat in the forge, but also because it seals the ceramic fibers that would be otherwise harmful to the user of the forge. While the cost increased because of the use of the expensive refractory coating, it was worth the expense because the user would then be able to operate the forge without a respirator. To close off the ends of the forge, the considerations were minimum ventilation and access. The minimum ventilation required for an atmospheric burner like the one that was chosen is at least seven times the area of the end of the burner. Since the burner that was chosen had a 1.77 square inch nozzle, the minimum ventilation required was 12.4 square inches. Because the nozzle was to be made using non-precise methods, a safe 14 square inches was used.

Burner. Since this forge was to be propane powered as opposed to charcoal heated, a fuel system had to be designed to deliver and burn the propane. The main piece of this design was the burner. Many different types of burners are available for propane forges, and there are many plans for making burners.

Burners can either be atmospherically aerated or blown. Atmospheric burners rely on venturi shaped burners to draw air in to the high-velocity, low-pressure streams of propane being injected into the forge.

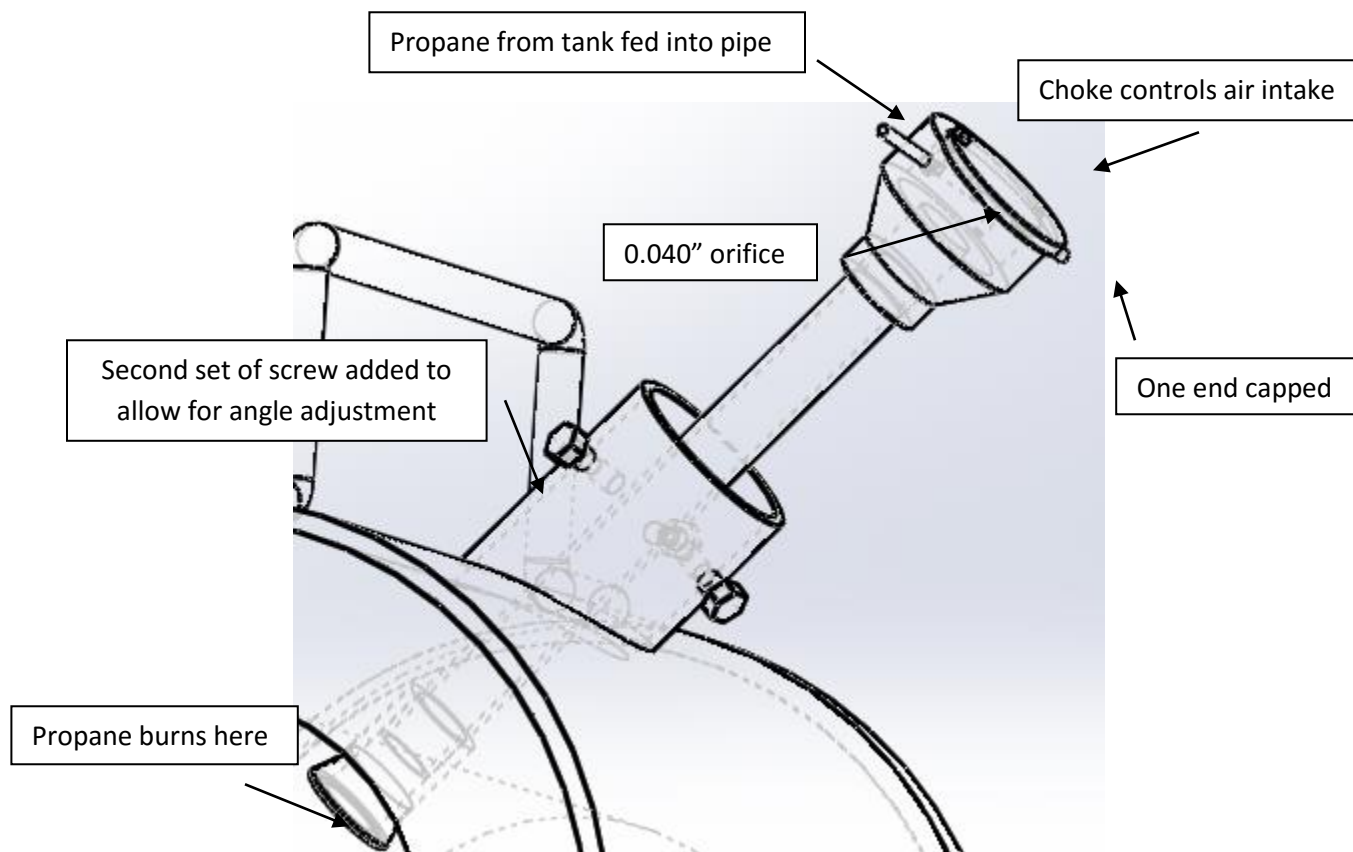


Figure 3. Burner Diagram

Atmospheric burners work great at low elevations and do not require any mechanisms to deliver the air. Blown burners rely on a compressor to force air into the burner. Blown burners are better for high elevation applications due to the thinner air at high elevations and the inability of atmospheric burners to deliver the proper amount of air because of that. The downside to blown burners is that they require another power source to run the compressor and therefore limit the portability of the forge. For a shop forge there is no problem with that, but for people that need to take their forge around with them for work (such as farriers who go out to ranches and work out of the back of their truck), it does not work quite so well. Because portability was a strong consideration, and the forge was to be used at or near sea-level, the atmospheric burner was chosen.

Construction

Body. The first step was to build the main body of the forge which everything else would attach to. To do this, a piece of steel had to be acquired large enough for the type of jobs the forge would be to handle. A common body is an old propane or Freon tank which results in a large, lightweight body but locating these can be difficult. A 10" diameter pipe was used because it would only require one burner for a 1' length as opposed to an old propane tank which would require two burners because of the extra 2" of diameter.



Figure 4. Cutting Body to Length

The pipe is much heavier than the tank would be, but also much sturdier. The pipe was then cut to a length of 1' in the band saw. The second step in constructing the body of the forge was to build and attach the burner holder. The burner holder was made out of a 2" diameter pipe section. The length of the pipe was cut to 4" and then one end of the pipe was cut at a 45 degree angle. The

purpose of the angled end of the pipe is for when it is attached to the body. The burner will heat up the forge best when it is at an angle inside the forge to create a swirling effect around the inside. To create the hole where the burner holder would go, the angled pipe section was held on the center of the body and traced with a scratch awl. The hole was then cut out with an oxy-torch and a piece of scrap sheet metal was placed inside the pipe to catch all of the molten metal to assist with cleanup. A half-round file was used to clean up the hole and smooth some angular edges so that the holder would fit well inside the hole.

Burner Holder. The burner holder was designed to have two sets of set screws so that the angle of the burner inside could be finely adjusted. Each row would have four set screws, so eight total holes had to be drilled into the burner holder. To locate the lines where the holes would be placed, an initial line was placed and then the others were measured off that one. The lines were to be offset to create an “x” pattern as opposed to a “+” pattern. The first line was eyeballed along one of the sides and scratched in using a square held onto the end of the pipe (which was in a vice) and a scratch awl. The next lines were marked by dividing the circumference by four and measuring each one along the edge of the pipe. After the four lines were established, each hole was located by measuring a prescribed distance from the edge of the pipe to the two holes along each line. Once the centers were marked with the scratch awl, they were set with a center punch. The pipe was then moved to the drill press to drill the holes. A pilot hole was used for each one and then the drill size that would fit the weld nut was used for the final hole.

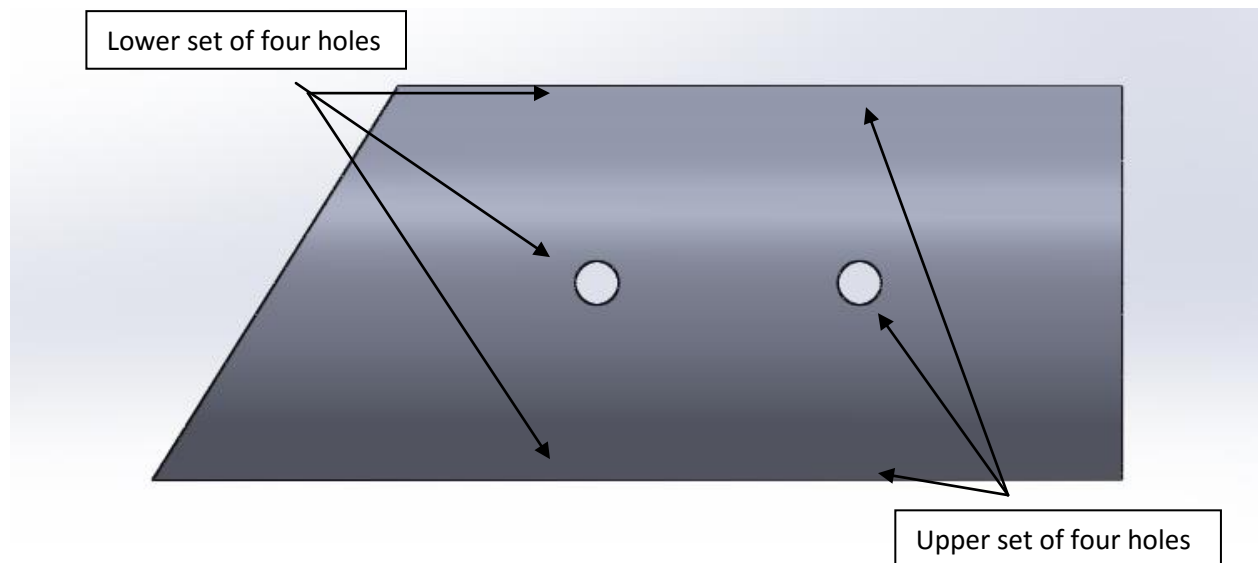


Figure 5. Laying Out Holes on the Burner Holder

The body was then clamped to the table with the cut hole on top. The body and the burner holder were cleaned up with a wire wheel to provide a cleaner weld. The burner holder was set at the desired angle then tacked into place with the MIG welder. Since the hole was cut with the torch and imperfect, gaps had to be filled with the welder. The MIG was then run around the burner holder in the hole until it was secure. At that point, the nuts had to be welded onto the burner holder. Each nut was hit with the wire wheel to remove the coating in preparation for the welding. Each nut was welded on two sides with the MIG.

Handle. A handle for the forge was constructed from some rebar because it was readily available. A piece of rebar was held in the vice and hammered with a sledge hammer to form 90 degree bends. The excess material was cut off in the band saw and then the handle was welded onto the top of the body with the MIG.

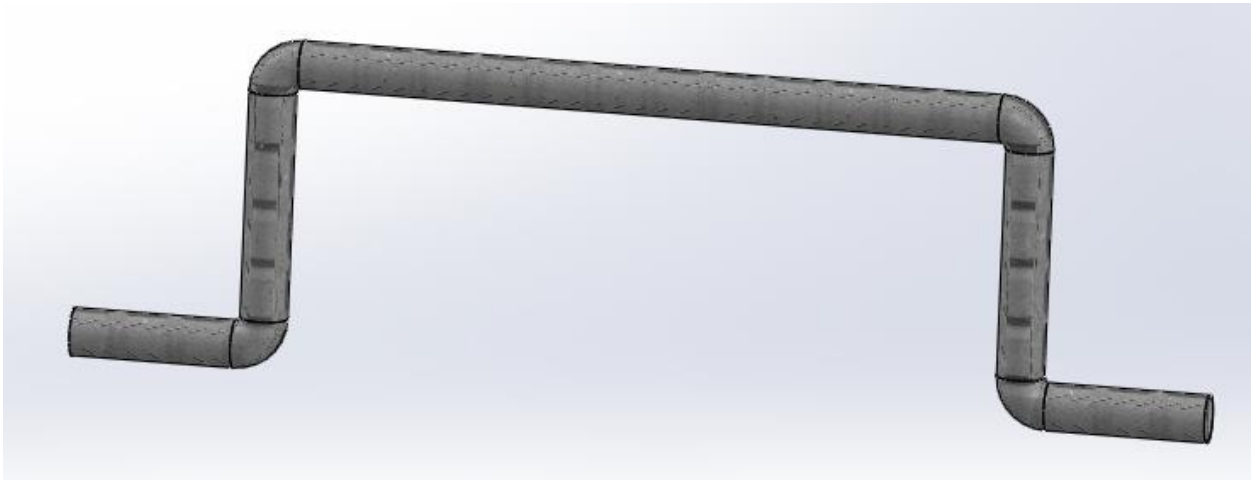


Figure 6. Rebar Handle Drawing

Feet. The feet of the forge were constructed from a piece of angle iron cut to length on the band saw and then welded to the bottom of the forge body at the point where the feet were flat and the forge body touched the ground in the middle. The foot was welded on both sides to create distance between the two welds so they could resist a bending moment.



Figure 7. Angle Iron Feet

Tool Rest. The tool rest was constructed by simply cutting a piece of rebar to length and then bending it 90 degrees with a hammer and vice. The tool rest attachment part was constructed by finding a small piece of pipe that could just fit the rebar into it without too much slop, cutting it to length, and then drilling a hole into the middle of it. The hole was sized so that the weld nut would fit and a bolt could be tightened and loosened to adjust or remove the tool rest bar. The attachment part was then welded onto the forge body flush with the face of the pipe.



Figure 8. Toolstand



Figure 9. Spray Painting the Body with High-Heat Spray Paint

Burner

The burner was constructed using basic plumbing parts and a little machining. For the air intake, the 1 1/2" to 3/4" galvanized bell reducer was marked a quarter inch below the large opening along center and a 9/64" hole was drilled clear through both sides. A hole was then drilled on only one side from the top face of the reducer down into the previously drilled hole so that both holes intersected each other. This hole was sized so that it could be tapped for an 1/4" NC bolt. The original hole had to be filed with a small round file in order to smooth out little pieces of metal from the second hole being drilled. The propane injector was simply created from an 1/8" brass pipe nipple with a #60 hole drilled in the center of it. The pipe nipple was then placed through the top of the bell reducer and capped on one end. The hole was oriented directly center pointing towards the small end of the reducer, and an 1/8" bolt was placed in the previously drilled and tapped hole to set the pipe nipple in place. A choke was then added on top of the large end of the reducer by taking an old lid from a jam jar and drilling a hole through one side of it so that it could sit evenly on top of the reducer and rotate about the bolt. An 8" long 3/4" black pipe nipple was then threaded into the small end of the reducer after cutting the threads off of one side. For the burner nozzle, a 3" section of 1" black pipe was used. A hole was drilled through center of one end of the pipe and the holes were tapped for a 1/4" NC set screw. To create the flared end of the nozzle, an oxy-torch was placed in a vice grip and used for a heat source. The end of the pipe was then heated up and worked around a small piece of round stock over and over until a flare with a diameter of about 1 1/2" was created.



Figure 10. Flaring the Nozzle over Round Stock

In order for the nozzle to fit over the black pipe nipple, the black pipe nipple had to be tapered using a bench grinder. The nozzle was placed on the black pipe nipple and set in place using two hex bolts. These hex bolts were later changed to set screws because the clearance between the nozzle and burner holder was not great enough to allow the burner to be installed. The brass pipe nipple was then connected to a 0-30psi propane regulator by a swivel fitting to a 3/8" hose. All the threaded connections in the burner were later doped to seal them.



Figure 11. Tapping the Set Screw Holes on the Burner Nozzle



Figure 12. Tapering Burner Tube on Bench Grinder



Figure 13. Fully Constructed Forge Body

Insulation. The entirety of the forge body was then cleaned with a wire wheel and spray painted with 2000 degree F rated high-heat black paint. Two layers of 1" thick 2400 degree F ceramic fiber blanket was then installed inside the forge body covering the entire inside surface. An "x" was then cut into the blanket from the burner holder hole. The outside diameter of the forge body was then traced onto a piece of ½" x 1' x 1' ceramic fiber board and cutout with a coping saw. A rectangular section was then cut out of the board. Later, paint had to be wire wheeled off in four spots so ½" pieces of ½" x ½" x ⅛" angle iron could be welded to the edge of the forge body in order to hold the fiber board in place. All surfaces of the fiber blanket and fiber board were then painted with a clay-like refractory material called ITC-100 and allowed to dry. Later, the forge had to be heated to its running temperature and then let cool three times in order to set the refractory coating. Six 2" thick firebricks were then acquired and stacked in front of the opening.



Figure 14. Rear Wall Installed with Front Bricks Stacked in Place



Figure 15. Forge with Fiber Blanket Installed



Figure 16. Painting ITC-100 Onto the Fiber Blanket

RESULTS

During the initial testing of the burner, it was found that flames shot out of all threaded fittings that weren't sealed, but after the problem was fixed and all threaded fittings were doped, the burner worked. A nice steady flame could be produced using the choke in conjunction with the regulator to establish a flame with a proper air fuel mixture. The flame could then be easily adjusted using both aforementioned devices to achieve the desired output.

The fully constructed forge was able to reach peak heat after being run for only a couple of minutes. The flame was easy to establish and control, and even after being run for a significant length of time, the handle and bottom of the forge did not get too hot to touch.



Figure 17. Forge User with Forged Knife

DISCUSSION

Cost Analysis

| Materials | | | |
|-----------|-----------------------------------|-----------|------------|
| Quantity | Item | Unit Cost | Total Cost |
| 1 | 10" Sch. 40 Steel Pipe x 1' | \$ 85.00 | \$ 85.00 |
| 1 | 3/8" Rebar x 3' | \$ 2.00 | \$ 2.00 |
| 1 | Brass Couplings and Caps | \$ 5.00 | \$ 5.00 |
| 1 | 1 1/2" to 3/4" Galvanized Reducer | \$ 3.00 | \$ 3.00 |
| 1 | 1/8" Brass Pipe Nipple x 3" | \$ 5.00 | \$ 5.00 |
| 2 | 6" Angle Iron 2" x 2" x 3/16" | \$ 2.00 | \$ 4.00 |
| 1 | 1/2" Pipe x 3" | \$ 1.00 | \$ 1.00 |
| 1 | Bolts & Screws | \$ 10.00 | \$ 10.00 |
| 6 | Fire Bricks | \$ 3.00 | \$ 18.00 |
| 1 | Rust-Oleum High Heat Spray Paint | \$ 5.00 | \$ 5.00 |
| 1 | ITC 100 (1/2 pint) | \$ 40.00 | \$ 40.00 |
| 1 | 1" Inswool Fiber Blanket 2' x 5' | \$ 36.00 | \$ 36.00 |
| 1 | 1/2" Insboard 1' x 1' | \$ 17.00 | \$ 17.00 |
| 1 | (Shipping for above 3 items) | \$ 42.00 | \$ 42.00 |
| 1 | 0-30 psi Propane Regulator (3/8") | \$ 32.00 | \$ 32.00 |

Total Materials \$
Cost = 305.00

| Labor | | | |
|-------|--|---------------|-------------|
| Hrs | Task | Per Hour rate | Total Cost |
| 25 | Research and Design | \$ 15.00 | \$ 375.00 |
| 35 | Materials Acquisition and Construction | \$ 70.00 | \$ 2,450.00 |
| 10 | Testing | \$ 15.00 | \$ 150.00 |

\$
Total Labor Cost = 2,975.00

The cost for the project was analyzed by breaking the process down into two distinct sources of cost: parts and labor. The parts were then counted as were purchased. The labor was counted using realistic assumptions for what it would actually cost a company. The materials acquisition and construction portion of the project was priced at \$70.00 an hour because that includes the hourly wage of the employee doing the work as well as the cost to own and run the equipment and tools required. The research and design portion of the project as well as the testing phase were priced at \$15.00 an hour because they do not require much machinery besides the product itself and can be done by an employee at regular wages.

The cost of the project was extremely high when labor is counted because of the man-hours invested. The actual cost of the parts required to construct the forge was relatively low, and the actual cost to build it was even lower because some parts were salvaged from the scrap pile, which meant not having to purchase some of the materials on the parts list. In the future, if this project were to be done again, the time needed to research and design it would be cut down to almost nothing more than familiarization with this report. A lot of time was wasted in the shop either waiting to use equipment or needing to be taught how to do certain things, and so time could be shaved off the construction phase by already knowing how to do all of the steps involved. Time for testing cannot really be cut, however, since this design is known to work, one could skip the lengthy testing phase and simply start using it after it is built and checked for basic proper function.

A small propane forge can be purchased for a few hundred dollars which beats the project cost by a longshot. The price for building one would be lower if more material was closely accessible and did not have to be shipped long distances, but someone without shop equipment would not be able to make it on their own.

RECOMMENDATIONS

For a future forge, a larger body as well as a second and possibly third burner would expand the capabilities of the forge. With a larger body, if even only by two inches, bigger pieces of metal could be accommodated in the forge but they would require that second burner. A third or fourth burner could be used to increase the reachable temperatures inside the forge. The thickness of the current body is also unnecessary and adds extra weight that the user has to deal with. For a body, an old propane tank would be a great option to go with. It would be lightweight as well as a larger diameter than the forge that was built. If the same amount of insulation was used, the outside metal would still not get warm. Welding to the thin gauge steel might be more challenging but overall it would be a better forge.

As far as burners go, the burner that was used works great. If the forge were going to be moved to a location with an elevation significantly above sea level, then a blown burner might be considered to replace the current atmospheric burner.

Another addition to the forge that would make it better would be an ignition system. Currently, the gas has to be turned on and lit with a barbecue lighter, but if there was some kind of small spark igniter inside the forge then it could be started with a simple button press. The difficulty in that is finding something that can withstand the heat, which was the reason that option was ruled out in the first place.

One other firebrick would be a great addition to the forge. It would be a 1/2" thick firebrick used for the floor of the forge to set pieces on so that the fiber blanket does not get damaged. It was a part of the original design but limited availability left it out of the final assembly.

A final recommendation would be to build a door for the front of the forge that has a rectangular port for minimum ventilation purposes, but could be opened to set and retrieve large pieces inside the forge.

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APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

Major Design Experience

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes the following fundamental elements. This project addresses these issues as follows.

Establishment of Objectives and Criteria. Project objectives and criteria are established to meet the needs and expectations of the client. See *Design Parameters and Constraints* below for specific objectives and criteria for the project.

Synthesis and Analysis. This project incorporates energy output calculations, thermal resistance calculations, and the consideration of alternative forging methods.

Construction, Testing, and Analysis. The propane forge was designed, constructed, and tested.

Incorporation of Applicable Engineering Standards. NFPA Codes which deal with liquefied petroleum gas.

Capstone Design Experience

The BRAE senior project is an engineering design project based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge/skills from these key courses.

- BRAE 129 Shop Skills and Safety
- BRAE 133 Engineering Graphics
- BRAE 152 SolidWorks
- BRAE 232 Ag Structures Planning
- BRAE 421/422 Equipment Engineering
- ME 302 Thermodynamics I
- ENGL 149 Tech Writing
- CHEM 124/125 Chemistry for Engineers

Design Parameters and Constraints

This project addresses a significant number of the categories of constraints listed below.

Physical. The forge dimensions ended being 12" x 14" x 15" and weighed about 50 lbs. The opening is 6" and has a tool rest.

Economic. Propane is cheaper than charcoal to purchase on a per energy basis.

Environmental. The propane emits less carbon than the dirty-burning charcoal forge.

Sustainability. Propane is from fossil-fuels and charcoal is from wood so it is not as sustainable as the old forge.

Manufacturability. The project was able to be constructed from the tools in the BRAE shops.

Health and Safety. The forge is only be used in outdoors or well ventilated areas because of the carbon monoxide output. Gloves and eye protection are also worn when using the forge.

Ethical. Operator safety was not neglected in order to meet other constraints such as Economics or Sustainability.

Social. The propane forge is noisier than the charcoal forge but produces less smoke.

Political. The propane forge helps reduce air pollution.

Aesthetic. The finished product is painted with heat resistant spray paint to protect from corrosion and give a nice appearance.

Other-Productivity. The forge is able to reach 2,300 degrees F.

APPENDIX B

DESIGN CALCULATIONS

1. Design Calculations for Heat Energy Output

Formula used:

$$\text{Burner output (BTU/hr)} = ((\pi * (\text{gas orifice})^2) / 4) * (\text{orifice discharge coefficient} / 144) * (21,407 * \sqrt{(\text{propane pressure})}) * 2,498 \text{ BTU/cu ft} * 60$$

Gas orifice = #60 drill bit = 0.040 in

Orifice discharge coefficient = 0.75

Propane pressure = 5 psi – 15 psi

$$\text{Burner output} = \underline{47,000 - 81,000 \text{ BTU/hr}}$$

2. Design Calculations for Heat Loss

R-Values (thermal resistivity)

$$R = 1/k$$

$$\begin{aligned} R (\text{steel body}) &= 1 / 40 \text{ BTU} \cdot \text{in} / \text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F} \\ &= 0.025 \text{ hr} \cdot \text{ft}^2 \cdot ^\circ\text{F} / \text{BTU} \cdot \text{in} \end{aligned}$$

$$\begin{aligned} R (\text{Inswool fiber blanket}) @ 2000 \text{ deg F} &= 1 / 2.34 \text{ BTU} \cdot \text{in} / \text{hr} \cdot \text{ft}^2 \cdot ^\circ\text{F} \\ &= 0.427 \text{ hr} \cdot \text{ft}^2 \cdot ^\circ\text{F} / \text{BTU} \cdot \text{in} \end{aligned}$$

$$\text{Composite R value} = (0.025 * 0.364 \text{ in}) + (0.427 * 2 \text{ in}) = 0.863 \text{ hr} \cdot \text{ft}^2 \cdot ^\circ\text{F} / \text{BTU}$$

$$0.836 \text{ hr} \cdot \text{ft}^2 \cdot ^\circ\text{F} / \text{BTU} * (1 / .5' * \pi) * (1 / 2200 ^\circ\text{F}) = 0.00024196 \text{ hr} / \text{BTU}$$

$$1 / 0.00024196 \text{ hr} / \text{BTU} = \underline{4,134 \text{ BTU/hr}} \text{ lost through the walls of the forge}$$

Exhaust losses = about 75-90% of the heat produced

*If only 1" of insulation was used:

$$\text{Composite R} = 0.4361 \text{ hr} \cdot \text{ft}^2 \cdot ^\circ\text{F} / \text{BTU}$$

$$0.4361 \text{ hr} \cdot \text{ft}^2 \cdot ^\circ\text{F} / \text{BTU} * (1 / .5' * \pi) * (1 / 2200 ^\circ\text{F}) = 0.0001262 \text{ hr} / \text{BTU}$$

$$1 / 0.0001262 \text{ hr} / \text{BTU} = 7,924 \text{ BTU} / \text{hr}$$

3. Design Calculations for Heat Transfer to Part

Specific heat of mild steel = 0.122 BTU/lb*°F

Low end (assuming fully open exhaust ports):

$$(47,000 \text{ BTU} / \text{hr} * .1) - 4,100 \text{ BTU} / \text{hr} = 600 \text{ BTU} / \text{hr} \text{ to part}$$

$$\text{For a 12 oz blade: } 0.122 \text{ BTU} / \text{lb} \cdot ^\circ\text{F} * (.75 \text{ lb}) / ((600 \text{ BTU} / \text{hr}) * (1 \text{ hr} / 60 \text{ min}))$$

$$= 109 ^\circ\text{F} / \text{min}$$

High End (assuming closed exhaust ports):

$$(81,000 \text{ BTU} / \text{hr} * .25) - 4,100 \text{ BTU} / \text{hr} = 16,150 \text{ BTU} / \text{hr} \text{ to part}$$

$$\text{For a 12 oz blade: } 0.122 \text{ BTU} / \text{lb} \cdot ^\circ\text{F} * (.75 \text{ lb}) / ((16,150 \text{ BTU} / \text{hr}) * (1 \text{ hr} / 60 \text{ min}))$$

$$= 2,940 ^\circ\text{F} / \text{min}$$

4. Design Calculations for Cost to Run Forge

At 5 psi:

$$47,000 \text{ BTU} / \text{hr} / (21,548 \text{ BTU} / \text{lb}) = 2.18 \text{ lb} / \text{hr}$$

$$2.18 \text{ lb} / \text{hr} / (20 \text{ lb tank} / \$20) = \$2.18 / \text{hr}$$

At 15 psi:

$$81,000 \text{ BTU} / \text{hr} / (21,548 \text{ BTU} / \text{lb}) = 3.76 \text{ lb} / \text{hr}$$

$$3.76 \text{ lb} / \text{hr} / (20 \text{ lb tank} / \$20) = \$3.76 / \text{hr}$$

*If only using 1" of insulation:

$$\text{Extra loss} = 7,924 \text{ BTU} / \text{hr} - 4,134 \text{ BTU} / \text{hr} = 3,790 \text{ BTU} / \text{hr}$$

Extra Cost =

$$3,790 \text{ BTU/hr} / (21,548 \text{ BTU/lb}) = 0.18 \text{ lb/hr}$$

$$0.18 \text{ lb/hr} / (20 \text{ lb tank} / \$20) = \$0.18/\text{hr}$$

APPENDIX C
CONSTRUCTION DRAWINGS

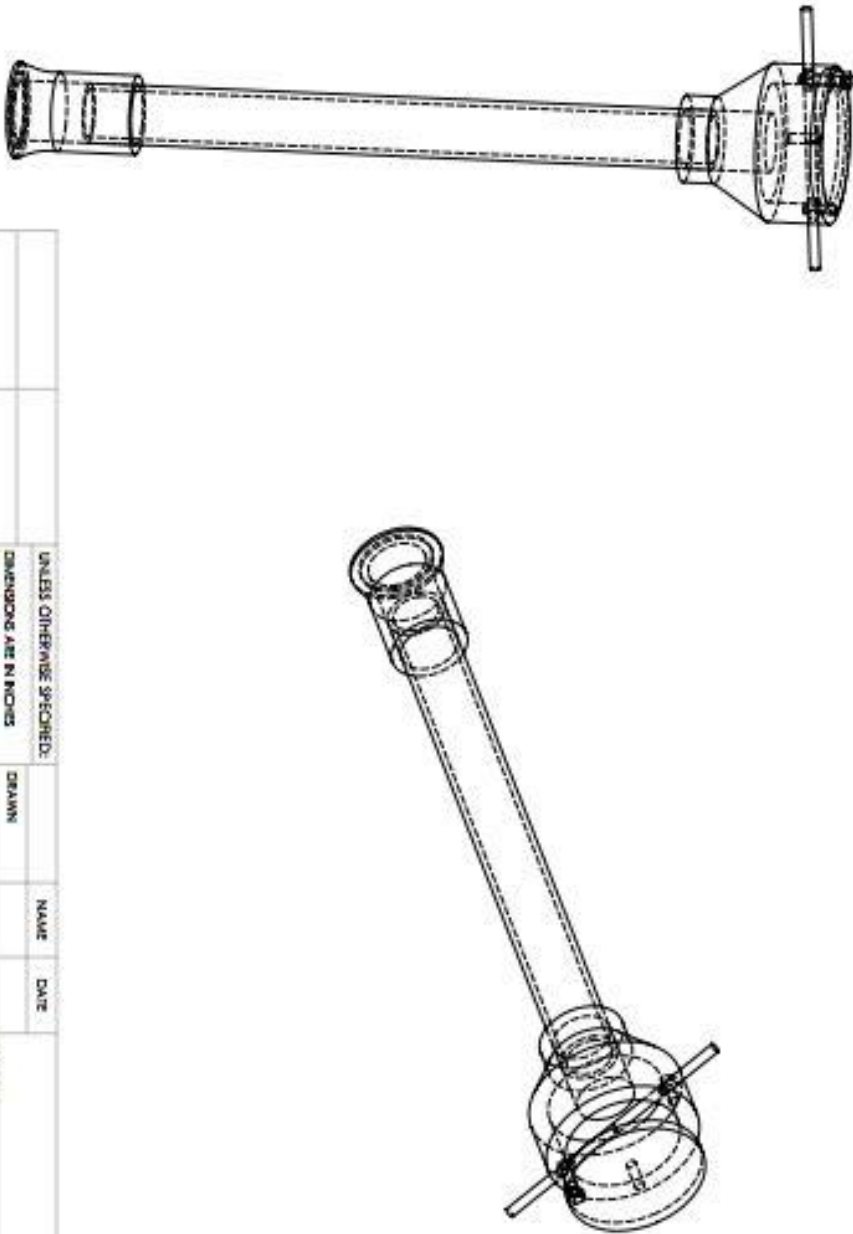


TRUE R5.00

TRUE R3.00



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|---|--|-----------|-----------|------|-------------------|---------|--------------|
| UNLESS OTHERWISE SPECIFIED: | | DRAWN | NAME | DATE | TITLE: | | |
| DIMENSIONS ARE IN INCHES | | CHECKED | | | | | |
| TOLERANCES: | | DWG APPR. | | | | | |
| ANGULAR: 1/4" CH 1 | | ENG APPR. | | | | | |
| TWO PLACE DECIMAL 1 | | | | | | | |
| THREE PLACE DECIMAL 1 | | | | | | | |
| INTERFERING GEOMETRIC TOLERANCING PER MATERIAL | | C.A. | COMMENTS: | | SIZE DWG. NO. REV | | |
| TYPICAL | | | | | | | |
| | | | | | | | |
| DO NOT SCALE DRAWING | | | | | SCALE: 1/8" = 1" | WEIGHT: | SHEET 1 OF 1 |
| APPLICATION | | | | | | | |
| USED ON | | | | | | | |
| TYPICAL | | | | | | | |
| PROPERTY AND CONFIDENTIAL | | | | | | | |
| THE INFORMATION CONTAINED IN THIS DRAWING IS THE PROPERTY OF THE DRAWING COMPANY AND IS NOT TO BE REPRODUCED OR TRANSMITTED IN ANY FORM OR BY ANY MEANS, ELECTRONIC OR MECHANICAL, INCLUDING PHOTOCOPYING, RECORDING, OR BY ANY INFORMATION STORAGE AND RETRIEVAL SYSTEM, WITHOUT PERMISSION IN WRITING FROM THE DRAWING COMPANY. | | | | | | | |
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| SolidWorks Student Edition. | | For Academic Use Only | | 5 | | 4 | |
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| UNLESS OTHERWISE SPECIFIED: | | DRAWN | | NAME | | DATE | |
| DIMENSIONS ARE IN INCHES | | CHECKED | | | | | |
| TOLERANCES: | | ENG APPR. | | | | | |
| FRACTIONAL: 1/16 | | MFG APPR. | | | | | |
| DECIMAL: .001 | | | | | | | |
| ANGULAR: .001° | | | | | | | |
| HOLE: .001 | | | | | | | |
| TWO PLACE DECIMAL: .01 | | | | | | | |
| THREE PLACE DECIMAL: .001 | | | | | | | |
| HIDDEN DIMENSIONING | | COMMENTS: | | | | | |
| TOLERANCING PER: | | | | | | | |
| MATERIAL | | | | | | | |
| FINISH | | | | | | | |
| DO NOT SCALE DRAWING | | | | | | | |
| APPLICATION | | | | | | | |
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| 5 | | 4 | | 3 | | 2 | |
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| TITLE: | | | | | | | |
| SIZE DWG. NO. | | | | | | | |
| A | | | | | | | |
| Burner | | | | | | | |
| SCALE: 1/4" = 1" | | | | | | | |
| WEIGHT: | | | | | | | |
| SHEET 1 OF 1 | | | | | | | |
| REV | | | | | | | |